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ABSTRACT

We are presently adding the capability to irradiate indirectly-driven Nova targets with two rings of illumination inside each end of the hohlraum for studies of time-dependent second Legendre (P_2) and time-integrated fourth Legendre (P_4) flux asymmetry control. The rings will be formed with specially designed kinoform phase plates (KPPs), which will direct each half of each beam into two separate rings that are nearly uniform azimuthally. The timing and temporal pulse shape of the outer rings will be controlled independently from those of the inner rings, allowing for phasing of the pulse shapes to control time dependent asymmetry. Modifications to the incident beam diagnostics (IBDs) will enable us to verify that acceptable levels of power balance among the contributing segments of each ring have been achieved on each shot. Current techniques for precision beam pointing and timing are expected to be sufficiently accurate for these experiments. We present a design for an affordable retrofit to achieve beam phasing on Nova, results of a simplified demonstration, and calculations highlighting the anticipated benefits.

KEYWORDS: beam phasing, kinoform phase plates, Nova, power balance, implosion symmetry

1. INTRODUCTION

An important element for achieving controlled inertial confinement fusion (ICF) in the laboratory is drive symmetry on target.[1-4] Drive symmetry is required in both a time-integrated and time-dependent sense. If the average flux is appreciably nonuniform, then capsule performance will be significantly impaired. A principal advantage of indirect-drive is the effective smoothing of short wavelength (or high Legendre mode P_n) flux asymmetries through use of a suitably large case-to-capsule ratio of radii. Longer wavelength asymmetries, principally P_2 and P_4, are not sufficiently smoothed at target center in standard hohlraums. Thus, particular attention is required to diagnose and control these two components of flux asymmetry in Nova hohlraums[5]. Our experience with Nova hohlraums has shown that tuning the lowest order (P_2) time-integrated flux symmetry can be accomplished by sliding the laser beam rings inward or outward along the hohlraum symmetry axis.[6,7] Our current capability to achieve lowest order time-integrated flux symmetry to within 1% on Nova meets the expected criterion for ignition on the proposed National Ignition Facility (NIF).[1,3] A more demanding task is to achieve minimal flux asymmetry excursions in time. High convergence implosions, such as those projected for the NIF, can be particularly susceptible to transient episodes of high flux asymmetry if auxiliary controls are not implemented.[3] Multiple laser cone configurations with independent power control potentially allow the use of beam phasing methods as a means of time-dependent control of lowest order flux asymmetry.[3, 8]

To help in understanding beam phasing conditions on the NIF, a beam phasing experimental campaign on Nova is under development. On Nova, the standard ten beam cluster will be split into four azimuthally symmetric rings (two outer and two inner) with the capability for independent laser power control between the outer and inner rings, i.e., beam phasing. Although the Nova beam phasing campaign will have independent rings as on the NIF, a limitation is that the laser entrance angles for the two sets of rings (with respect to the hohlraum symmetry axis) will remain at nearly 50 degrees. On the other hand, the envisioned time-dependent symmetry control effort on Omega[9] will have more NIF-like ring angles but not independent pulse shaping - at least over the near term. However, a modest level of symmetry control is still possible with this configuration by sensibly utilizing time-delays between the sets of rings, i.e., beam-staggering. Together, the projected symmetry control efforts on Nova and Omega should complement each other and potentially provide a reliable extrapolation to beam phasing conditions expected on the NIF.

2. LASER MODIFICATIONS

To achieve beam phasing on Nova, we will split each of the ten beams into two parts. Each half will contribute to a different ring inside the hohlraum with the use of specially designed KPPs. Since we routinely propagate different pulse shapes on different beamlines for backlighting purposes, only minor modifications are necessary for different pulse shapes to propagate down each half of each beamline. This will allow the outer and inner rings to have any two separate pulse shapes that we are capable of producing on Nova[10].

As illustrated in figure 1, the two pulses enter the Nova preamplifier section separated in time by 20 ns. A Pockel's cell followed by a rotator and a polarizer sends the first pulse down a separate path, which contains an optical delay line that enables an adjustment to the time shift between the two pulse shapes. The time shift between the two pulse shapes on target is constrained only by the Pockel's cell gates in the main beamlines, which require that the total pulse width be no longer than 10 ns. Each beam encounters an apodized aperture which restricts each to its respective half of the full aperture. The two beams are then recombined with a polarizer. A quartz rotator in one half realigns the polarization with that of the other half for propagation through the amplifier chains.

KPPs,[11] which are fabricated on Nova debris shields, provide a convenient method of introducing, in effect, an optical wedge to direct half of each beam to a different spot on the target. In addition, the design of the far field profile produced by KPPs is extremely flexible. To within the constraints of fitting the beams through hohlraum laser entrance holes (LEHs) and distortions due to phase aberrations on the beams, KPPs will be able to shape the far field profile of each half beam into an approximately 72 degree segment of a ring when projected onto a hohlraum wall with a 50 degree angle of incidence. This will create rings that are nearly uniform in the azimuthal dimension, significantly reducing the m=5 asymmetry and the Rayleigh-Taylor instability growth. Fitting the beams through the LEH without getting closer than 150 μm from the edge is important in preventing blockage of the beams late in time due to plasma filling. To minimize the beam footprints at the LEH, the KPPs are designed with an additional wedge which breaks each ring segment into two pieces that cross near the LEH (Fig. 2.) Also, the plane of best focus will be set to correspond to the LEH. The reference contains more details of the KPP design[11].

Three more modifications to the laser have been completed well before the rest of the beam phasing project because they are also needed for the implementation of beam smoothing on all ten beams[12]. The plane which contains the aperture that spatially defines the two halves of the beam requires image relaying through the system to be certain that the pulse shapes are separated at the KPP. Lenses, added to the preamplifier section and six individual beamlines, sharpen the image of the split (fig. 3.) Secondly, the footprint of six of the beams already had the correct orientation on target. The existing amplifier disk splits on these beamlines are oriented along the short axis of the hohlraum, which corresponds to the desired pulse shape separation direction. For these four beamlines, the pulse shape separating aperture in the preamplifier section is aligned with the disk split. The orientation of the disk split on four of the beams is oriented at 45 degrees relative to the hohlraum axes. These four beams are rotated in the front end of the laser chains with kinematically mounted out-of-plane mirrors whenever beam phasing or beam smoothing is required. A consequence of the beam rotation is that those beams contain a second apodized split, which will not be observable in the far field due to the KPPs. The reduction of < 10% in amplifier fill factor will not present a problem at the energies required for beam phasing experiments. Thirdly, hardware has been installed to mount additional debris shields in the target chamber to protect the beam phasing and beam smoothing KPPs from target debris.

We performed a simplified test on two beams without KPPs to demonstrate that Nova could be modified for beam phasing experiments. Figure 4 shows that we successfully propagated different pulse shapes down each half of two beamlines in the proper orientation on target.

3. PRECISION OPERATIONS AND LASER DIAGNOSTICS

Precision Nova operations, including power balance[13], beam pointing[14] and synchronicity[15], will be important for beam phasing. The diagnostics will require modifications to properly perform precision beam phasing operations. The IBDs on Nova routinely measure the energy and temporal profile of each beam after frequency conversion. A 1% back reflection from the target chamber focus lens provides an entire beam sample that focuses to a diameter of approximately 19 cm on a diffuser located behind an obscuration in the center of the incident beam. The diffuser provides an image plane for a cluster of diagnostics which currently contains three diodes to measure the first, second and third harmonic energies, a fiber optic coupling to a streak camera to measure the temporal profile, and a fast photodiode coupled through a 6 GHz transient digitizer to provide a redundant temporal profile measurement. We plan to use modifications of the existing diagnostics to provide energy and temporal profile measurements of each half of each beam to gauge how successfully the power in the segments of each ring are balanced. The diodes which currently measure the first and second harmonic energies will be used to measure the third harmonic energy in different halves of the beam. This is possible because the optical system that images the diffuser onto the diodes contains an image relay plane of the diffuser. In this plane we will place an aperture that blocks half of the image of the beam. Precise alignment of the aperture relative to the split in the beam will be achieved by back illuminating the imaging system with a light source onto the diffuser. The diode that currently measures the third harmonic energy will remain. This will provide a measurement of the total energy in both halves for redundancy. Calibrations of the energy diodes relative to the inline 44 cm calorimeters will be performed on half of each beam per shot. This requires firing the amplifier chains twice to calibrate all of the IBD energy diodes.

The other components of power balance are the relative pulse shapes and timing among the beam halves. The timing among the beam halves which form each set of rings will be measured using current techniques[15]. The inner rings will be fired onto a disk target which is imaged with an x-ray streak camera. Subsequent shots will measure the relative timing of the outer ring segments and the timing of the outer rings relative to the inner rings. This technique has been demonstrated with whole beams to maintain synchronicity to within 10 ps rms.

The third harmonic pulse shapes will be measured with existing diagnostics. The only modification will be the addition of an aperture to limit the fast photodiode spatial view to only half of the beam. Since the optics that couple the light to the streak camera are too small to add a limiting aperture, the streak cameras will measure the sum of the pulse shapes in both halves of the beams. The temporal profile of the other half will be obtained by subtracting the profile measured with the photodiode from the profile measured with the streak camera, scaled by the energy measurements. This method is not as accurate as a direct measurement, especially since the temporal resolution of diode/6 Ghz transient digitizer systems is about 80 ps longer than that of streak cameras. If better accuracy is desired, it may be possible to add an additional diagnostic to directly measure the temporal profile of both halves of each beam at substantial extra cost. Nova has been routinely operating with power balance errors within 5% rms in the peak and 10% rms in the "foot" of shaped pulses. Increased uncertainties in measured temporal profiles and energies will likely increase power balance errors to 7% rms in the peak and 12% rms in the "foot."

Precision beam pointing will be achieved using the current procedures[14]. Calibration shots are used to measure differences between the pointing of alignment and pulsed beams. The beams are fired at a disk containing fiducial holes. An x-ray image of the target is used to compare the point at which each beam hits the target with its aim point. Experience with performing pointing calibration measurements with binary random phase plates shows that the KPPs should not significantly affect our ability to maintain a pointing accuracy of 35 μm rms among the ten beams. Since the two halves of each beam will move together, a far field image of only one half of each beam will be needed to verify pointing accuracy.

4. SIMULATION RESULTS

Simulations have been performed to calculate the laser parameters that optimize the reduction of flux asymmetries on an implosion capsule, which has a radius of 220 μm and a wall thickness of 25 μm, within the geometrical constraints of beam phasing on Nova[8]. Figure 5 shows the results of calculations that predict nearly a factor-of-four decrease in the time-dependent P_2 flux asymmetry up to 1.9 ns for optimally pointed beam phased pulses which, when summed in time, are equivalent to the commonly used Nova pulse shape 22. Also shown are the results of calculations to determine the optimal ring separation distance for time-integrated P_4 flux asymmetry reduction. Based upon these calculations, we have chosen a ring separation distance of 300 μm, which is anticipated to also reduce the time-integrated P_4 component by a factor-of-four.

5. CONCLUSION

The capabilities of the Nova laser continue to be enhanced. Beam phasing on Nova will make experiments involving the control of time-dependent flux asymmetries possible before the NIF is completed. We expect to fully implement this project near the end of CY 1997.

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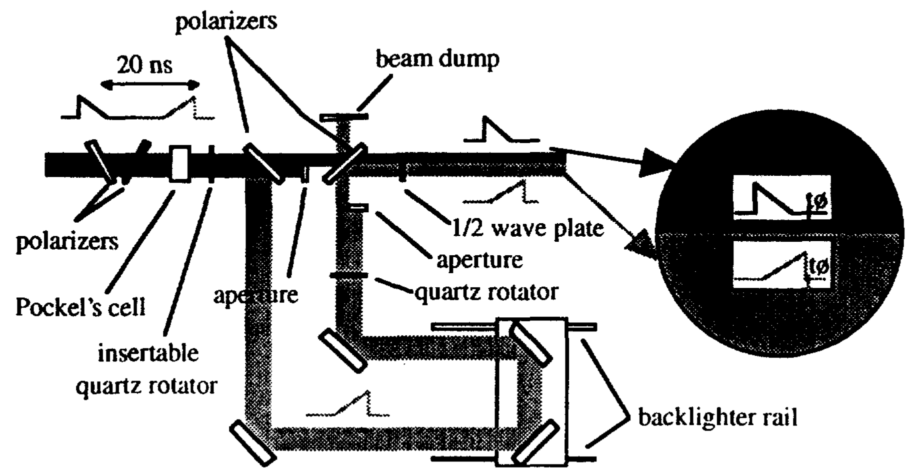

Fig. 1. This schematic represents optics added to the Nova preamplifier for beam phasing. The two simplified pulse shapes in the illustration are transformed from being separated in time by 20 ns to each filling half of the beam spatially with an adjustable time shift.

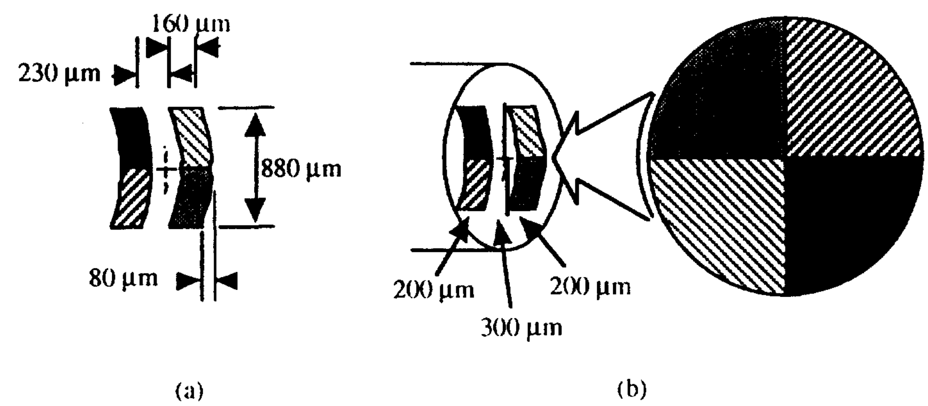

Fig. 2. a) The far field spots projected normal to the beam are curved so that they form rings on the inner wall of the hohlraum. b) Beams illuminate two 200 µm wide rings separated by 300 µm. Each ring is split into two parts which cross near the LEH to maximize clearance.

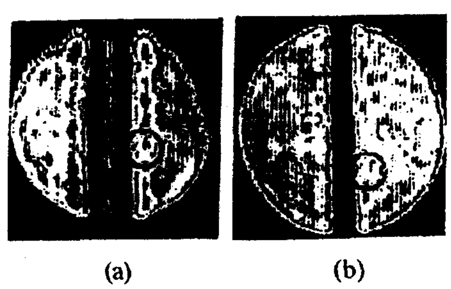

Fig. 3. a) The near field beam profile at the input sensor of beamline 7 without the added relay optics is highly diffracted. b) The relay optics sharpen the image of the split in the beam. The plane imaged by the input sensor is approximately relayed to the target chamber.

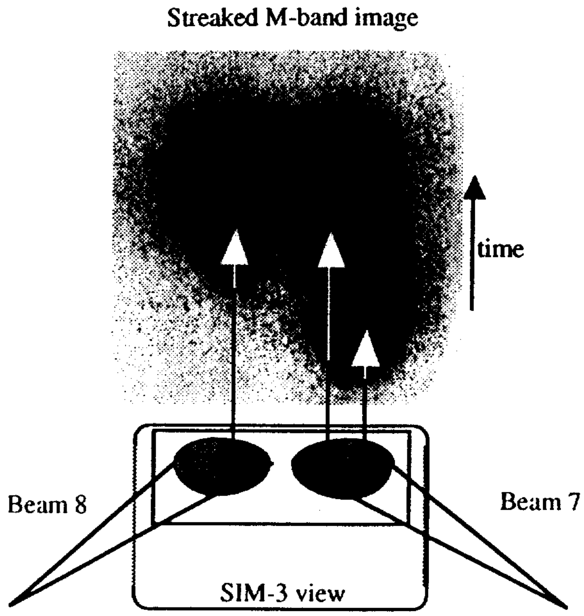

Fig. 4. A simplified single-shot demonstration on two arms shows that we can produce beam phasing on Nova. The two x-ray streak camera images to the right show the two separately pulse shaped halves of beamline 7 separated in time. The second half of beamline 8 was well timed with that of beamline 7. The first half of beamline 8 was mistimed on this shot, an easily correctable problem.

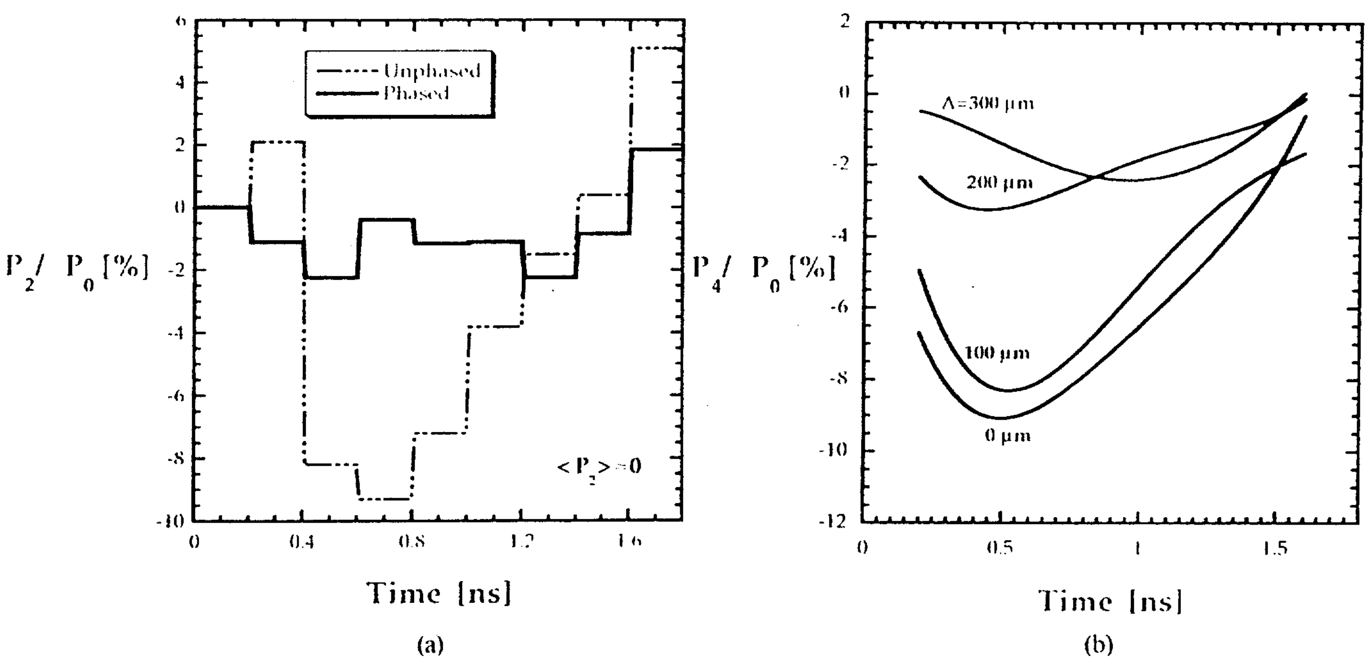

Fig. 5. a) The second Legendre coefficient of ablation pressure asymmetry vs. time is shown with and without beam phasing. b) The fourth Legendre coefficients ($<P_2>=0$) of ablation pressure asymmetry vs. time are shown for various values of ring separation. The laser and target parameters for these calculations are as follows: Hohlraum: length 2300 μm, radius 800 μm, 100% LEH; Capsule: radius 220 μm, wall thickness: 25 μm; Combined pulse shape: PS 22; Total energy: 28 kJ.